AN INSTRUMENT FOR MEASURING THE RHEOLOGICAL PROPERTIES OF AGRICULTURAL COMMODITIES

Robert W. Decker*
Agricultural Engineer
Quality Evaluation Section
Biological Sciences Branch, Marketing Research Division,
U.S. Department of Agriculture, Beltsville, Maryland

Paper to be presented before joint
farm structures an rural electric program,
Winter Meeting ASAE, Chicago, Ill.

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Robert W. Decker*
Agricultural Engineer
Quality Evaluation Section
Biological Sciences Branch, Marketing Research Division,
U.S. Department of Agriculture, Beltsville, Maryland

The quality of agricultural products can be determined in many ways using a wide variety of equipment and procedures. Most methods, however, will fit into one of two general categories, physical methods or chemical methods, although some procedures include both. One method of evaluating quality by physical tests is that of measurement of the various rheological properties, that is, those properties of hardness, stiffness, toughness, and other less well defined characteristics usually determined by a sense of feel. 1/

Although a measure of these properties can be obtained by chemical and physical-chemical methods such as fiber or moisture content determination and similar tests, other factors more difficult to determine also affect the rheological properties. Moreover these tests are often difficult to conduct, require a variety of specialized equipment, and are time consuming. Direct measurement of these rheological properties is therefore desirable whenever possible.

Many devices have been developed that directly measure some of these characteristics. However, these have usually been designed for use with one specific product, thereby greatly restricting their use. Examples of this type of apparatus are the tenderometer and maturometer for peas, and various fibrometers, texture meters, penetrometers, and viscometers for other products. In an attempt to develop an instrument applicable to a wide variety of products and tests, the shear-press was designed and constructed

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at the University of Maryland. 2/ Later modifications and revisions resulted in an instrument which found increasing application in both research and commercial organizations. This paper described modifications of one of these instruments for electrical indication and recording.

Description of the Unmodified Shear-Press

As indicated in Figure 1, the shear-press consists fundamentally of a box to hold the sample, a hydraulic system to drive a shearing head through the sample, and a measuring device to indicate the force required to shear through the sample.

The Sample Box. For products such as asparagus, the sample box consists of a slotted base and two grooved sides, while that for products of small unit size is completely enclosed with a slotted top and bottom and grooved sides.

The blunt-edge blades of the shearing head are guided by the grooved sides of the sample box and are of sufficient length to pass completely through it. A single thin blade is used with the asparagus cell while those for the standard cell are 1/8" thick with 1/8" spaces between blades. Volume of the standard cell is approximately 17.2 cu. in.

The Hydraulic System. The hydraulic system consists of four units: a reservoir in which the pump and pressure relief valve are mounted, a flow controller to change the volume of oil flow to the cylinder, a control valve to regulate the direction of oil flow to the cylinder, and a double acting hydraulic cylinder.

The Measuring Element. The hydraulic cylinder is so constructed that the force is transmitted to a spring dynamometer and then to the shearing head. Compression of this dynamometer spring is indicated by a dial gage calibrated in pounds total force.

Modifications of the System for Recording

Although the maximum force required to shear through a sample had proved very useful as a rapid, reproducible measure of rheological properties of a product, it was believed that further information could be obtained from a continuous record of this force variation. It was hoped that information could be obtained about the individual units of the sample as well as its overall characteristics.

In addition to obtaining further information about the sample, force recording showed promise of reducing several sources of error in the previous system. Human error resulted from misreading the dial gage scale and from failure to catch the maximum indication. Use of a maximum reading gage hand reduces this error but further increases error due to friction in the dial gage mechanism. Since a permanent record is produced, the data can be analyzed at some future time, thereby eliminating much of the operator error.

Addition of a transducer to the system to give an electrical output proportional to total force seemed the most desirable solution since minor modifications would allow comparison to data previously obtained. An electrical system was selected since amplification, indication, and recording could be accomplished by standard units which are both convenient to use and rugged in nature. Sufficient electrical amplification can conveniently be made available to allow selection of convenient ranges for different products, thereby extending application of the shear-press to a greater variety of products.

While a recorder may not be required for commercial applications, electrical indication remains advantageous. Since range changing on the mechanical system requires a number of expensive calibrated dynamometers, a

multi-range instrument utilizing an electrical transducer should be no more expensive since only one dynamometer is required. In addition, the force can be indicated on a precision panel meter, thereby increasing both convenience and accuracy. When a recorder is used, the data can be adjusted for variation of sample volume since the recording is essentially plotted as a function of spindle travel and the point at which the sample is contacted can be determined conveniently.

Chief disadvantage of the electrical instrument system is increased complexity and maintenance. However, this need not result in greater operating complexity since the number of operating controls can be reduced through good design of the amplifier-indicator. Initial cost of a single range instrument would be somewhat higher than that of a mechanical system, but not of a multi-range instrument. Operating cost would be considerably increased because of recorder chart consumption.

Details of Construction and Operation

The modified shear-press system is shown in block form in Figure 2. Except for the electric motor, all components to the left of the line separating electrical and mechanical components were added to the shear-press in the recording modifications. Details of construction are shown in Figure 3. Component numbers from this figure are used in the following description of construction and operation.

Shearing of the sample occurs as the shearing blades carried by the piston (1) are propelled through the sample. Force is transmitted through the rod (2) to the dunamometer spring. (3) Movement of the end of this spring is proportional to theforce on the sample. This motion is transferred to the core (4) of the transducer by a link bearing on the lever (5).

One end of this lever is fixed solidly to the dynamometer, the other rests on a tapered bushing (6). Movement of this bushing along the lever by the adjusting nut (7) moves the core relative to the dynamometer spring, thereby giving a fine mechanical zero adjustment to the system. A similar effect is obtained by rotation of the shell (8) thereby displacing the transformer windings relative to the core and effecting a coarse mechanical zero adjustment.

Since it was desirable to be able to measure forces of a few pounds, it was necessary to incorporate the weight of the shearing head, piston, and rod in the force measuring system. This was done by coupling them to the dynamometer spring through a cone bushing (9) and rubber washer (10). This rubber washer is sufficiently compressed that contact is maintained between the cone bushing and the rod, thereby eliminating a "dead point" as the system goes from tension to compression. The spherical end of the rod bearing on the cone surface of the cone bushing reduces end friction effects and maintains alignment as the dynamometer spring compresses.

The transducer, a commercial linear variable differential transformer, consists of a primary winding (11) and two secondary windings (12). These secondary windings are so connected that the output voltage is the difference between the induced voltages. Power to excite the primary is furnished from the 6.3 volt a.c. winding of the displacement indicator power transformer. With the core centered between the two secondary windings, equal and opposite voltages are induced in the secondaries and there is no output voltage. Movement of the core from the center position unbalances the induced voltages and an output voltage is produced of magnitude proportional to the displacement, and whose phase depends on the direction of motion from the center position.

This signal from the transducer is amplified and phase detected in the displacement indicator. Incorporated with the amplifier system is an attenuator giving three ranges in decade steps. Also included is a calibrating circuit providing means of maintaining instrument calibration as circuit components change with temperature, age, etc.

The output of the indicator is displayed on a precision panel meter and is also brought to an external recorder jack. The instrument was designed to drive a millivolt servo recorder, or, with additional amplification, a galvanometer recorder of approximately 1400 ohms coil resistance. The displacement indicator was modified according to instruction from the manufacturer to obtain additional amplification since a galvanometer recorder of this type was available.

Since the recorder chart is driven by an electric motor, thereby giving a plot of force with time, the recorder was equipped with a solenoid margin pen to give a reference to the position of the shearing head in the sample box. This solenoid pen is actuated by a switch attached to the moving spindle. As the spindle travels downward, the margin pen switch (13) is tripped by the stationary margin pen switch actuators (14) to give a pip on the chart margin each 0.2 of the total travel through the sample. Use of a hinged actuator eliminates operation of this switch in the reverse direction.

To reduce chart consumption, the chart drive motor is controlled by a second switch immediately behind the margin pen switch. This chart drive switch (15) actuates the chart motor during the downward stroke only, the hinged contactor preventing actuation on the return stroke.

Performance of the System

Utilizing a 2500# capacity dynamometer, the maximum sensitivity of the system is 4 pounds full scale. However, operation at less than maximum

sensitivity is desirable since frictional effects in the sample box and on the piston surface reduce the accuracy and reproducibility. Adjustment of the amplifier gain for 50 pounds full scale reduces these effects to less than 5% of the full scale value. Absolute accuracy is determined by the accuracy of the calibration. This is easily accomplished by use of the spring dynamometer which is normally in the system.

Linearity is within 1% of the full scale reading. Response time is approximately 0.7 seconds. Resolution and reproducibility are better than 1% of full scale at less than 50 pounds sensitivity. Steady drift of the electrical zero did not exceed 0.8% of full scale per hour. Some mechanical zero drift is present at high sensitivity but this is mostly due to vibration and is of a random nature.

Details of Operation

For stable operation, approximately 30 minutes warm-up is required. With the operation selector switch in zero position, the electrical zero of the system is set by the displacement indicator zero control. The operation selector switch is then changed to the sensitivity range being used and the mechanical zero of the transducer is adjusted. The operation selector switch is next set at calibrate position and the sensitivity control adjusted to full scale deflection. The force required for a full scale deflection can be increased by setting the sensitivity control to less than full scale. For example: setting the sensitivity control until half scale is indicated requires twice the force of the former setting for a full scale deflection. The operation selector switch is then returned to the sensitivity range to be used and the system is ready for operation.

Nature of the Data Obtained

A detailed interpretation of the data will be reported in another paper and is not being attempted at this time. Figure 4 illustrates the type of information obtained using this system for four different commodities. These curves do not end at zero pounds force since the shear blades are continuing through the bottom grids of the sample box after passing through the sample. This requires considerable force since portions of the material are being carried along.

Acknowledgements

The author acknowledges the cooperation of M. M. Moorhead of Daytronic Corporation on modification of the displacement indicator and of Karl H. Norris and Charles K. Powell for assistance in design and construction of the modified system.

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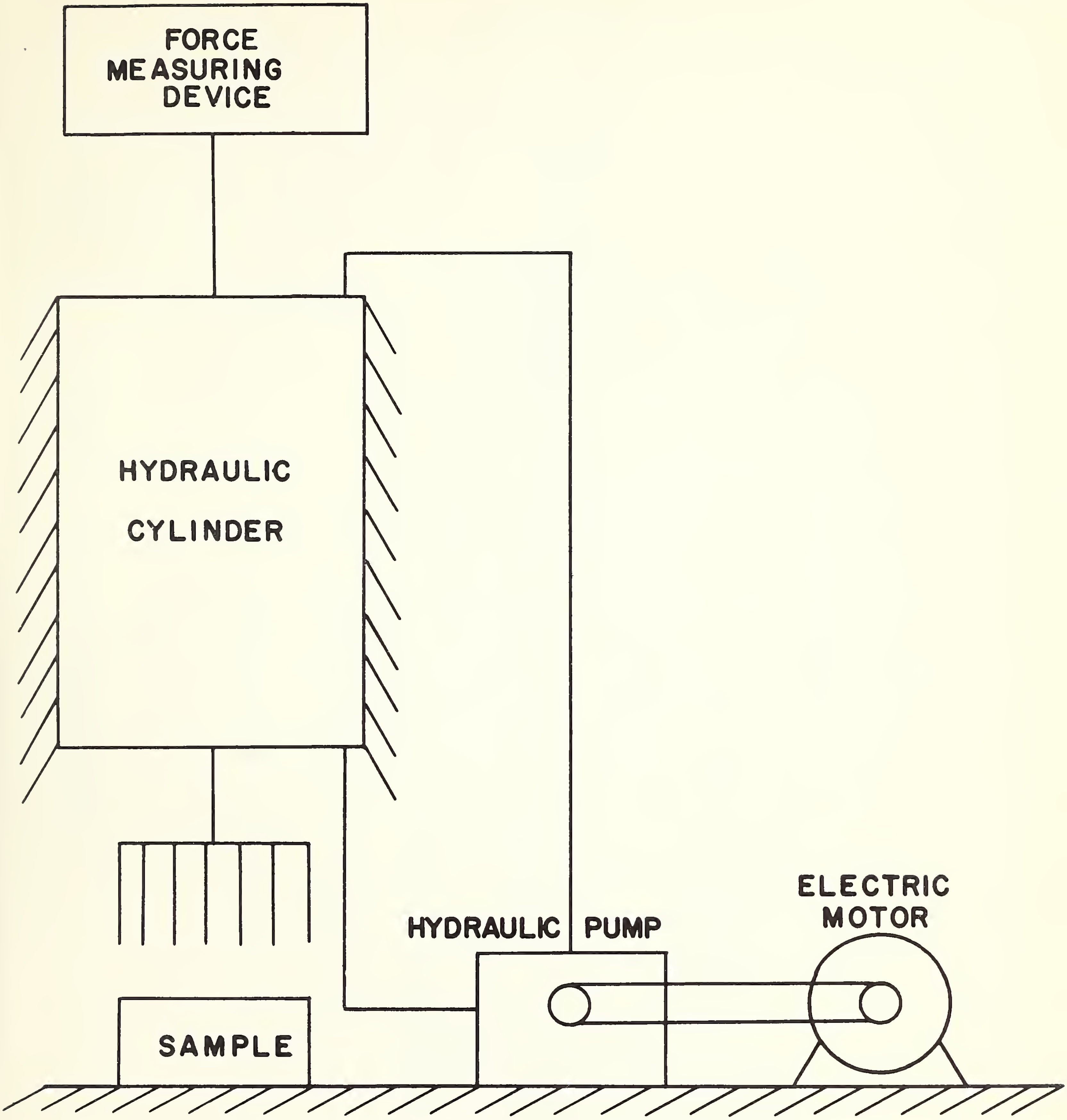

FIGURE 1 - Simplified block diagram of shear press.

SHEAR PRESS SYSTEM DIAGRAM

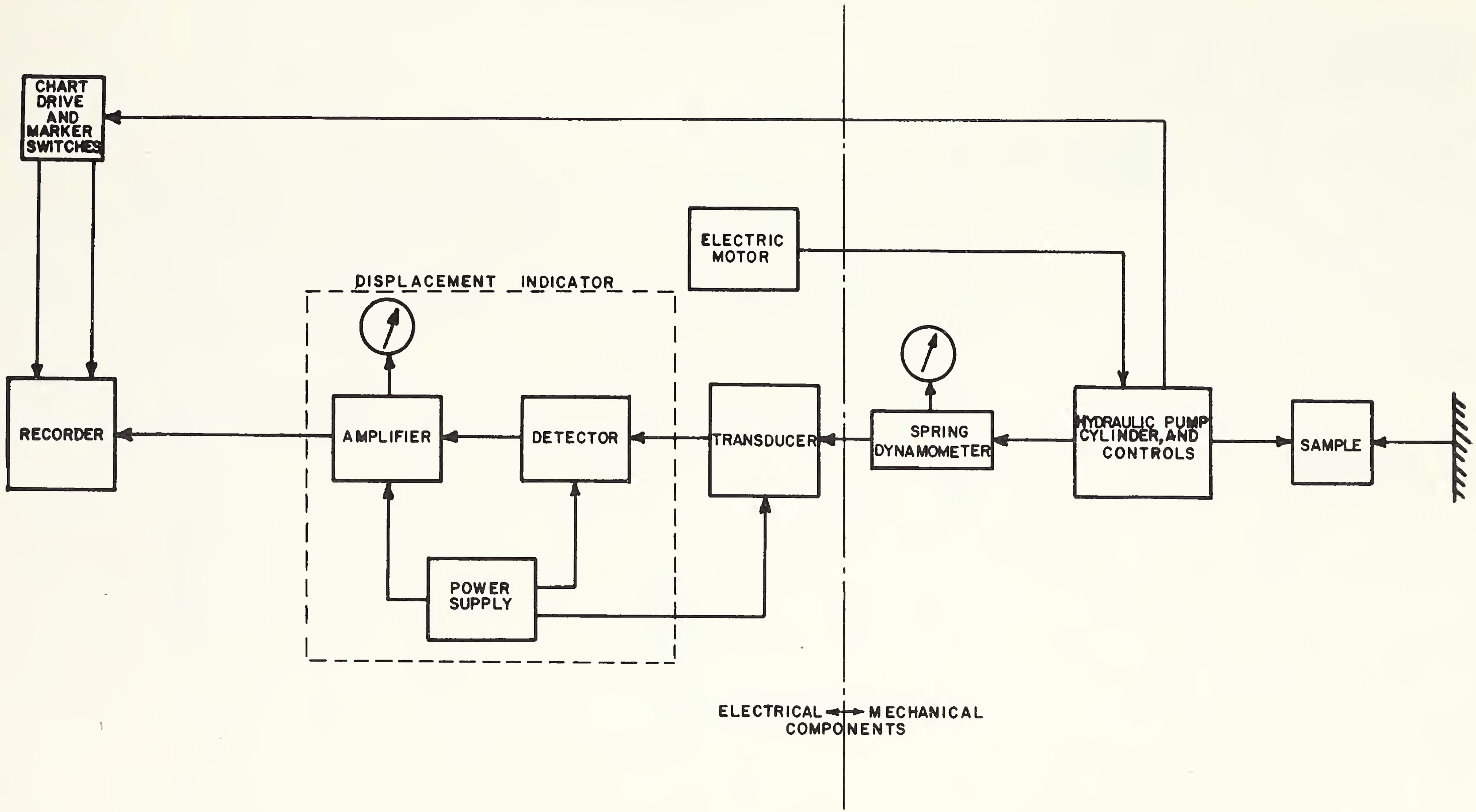

FIGURE 2 - Block diagram of modified shear-press system.

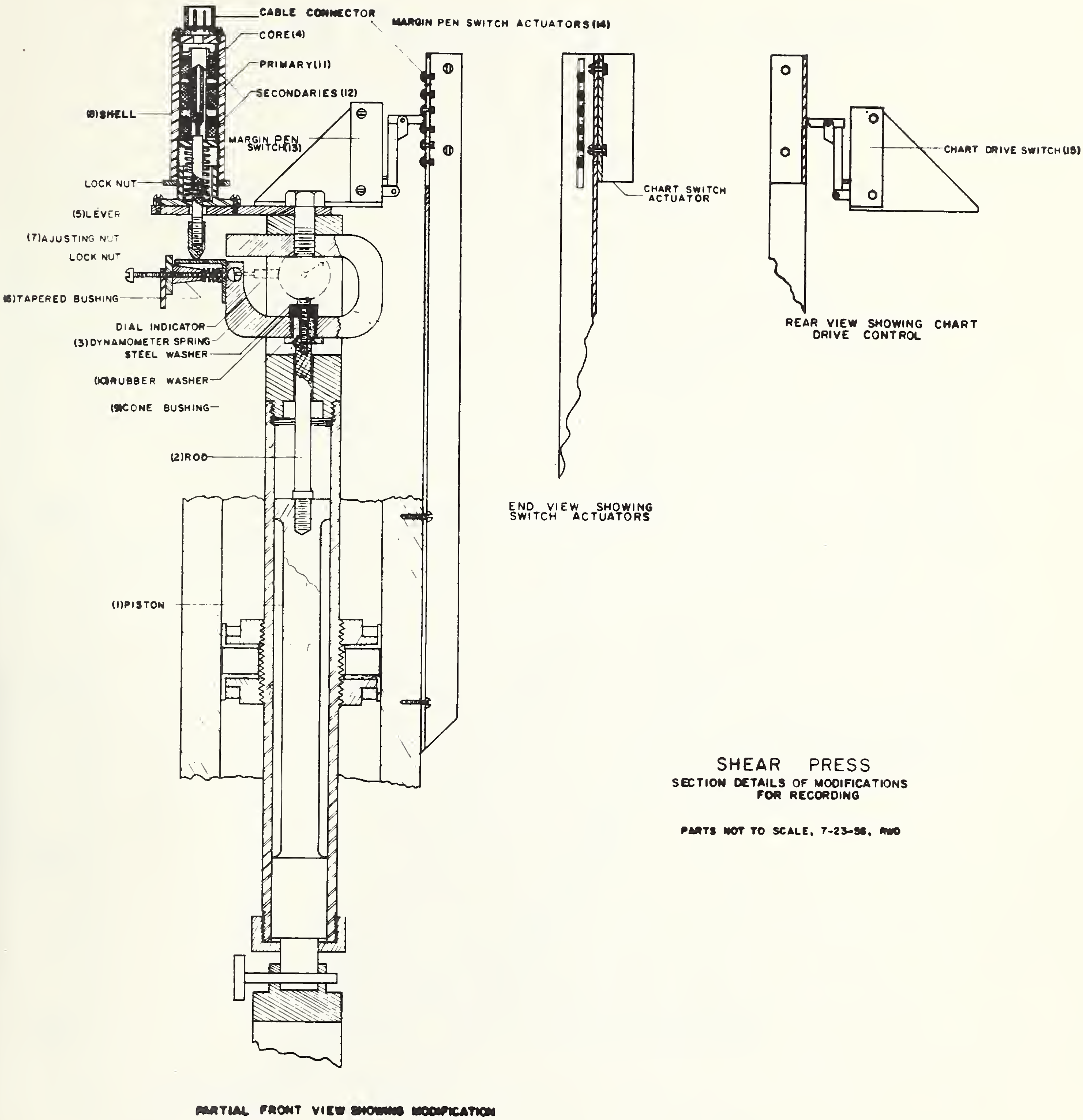

FIGURE 3 - Construction details of hydraulic cylinder, dynamometer, and transducer.

SHEAR PRESS FORCE DIAGRAM

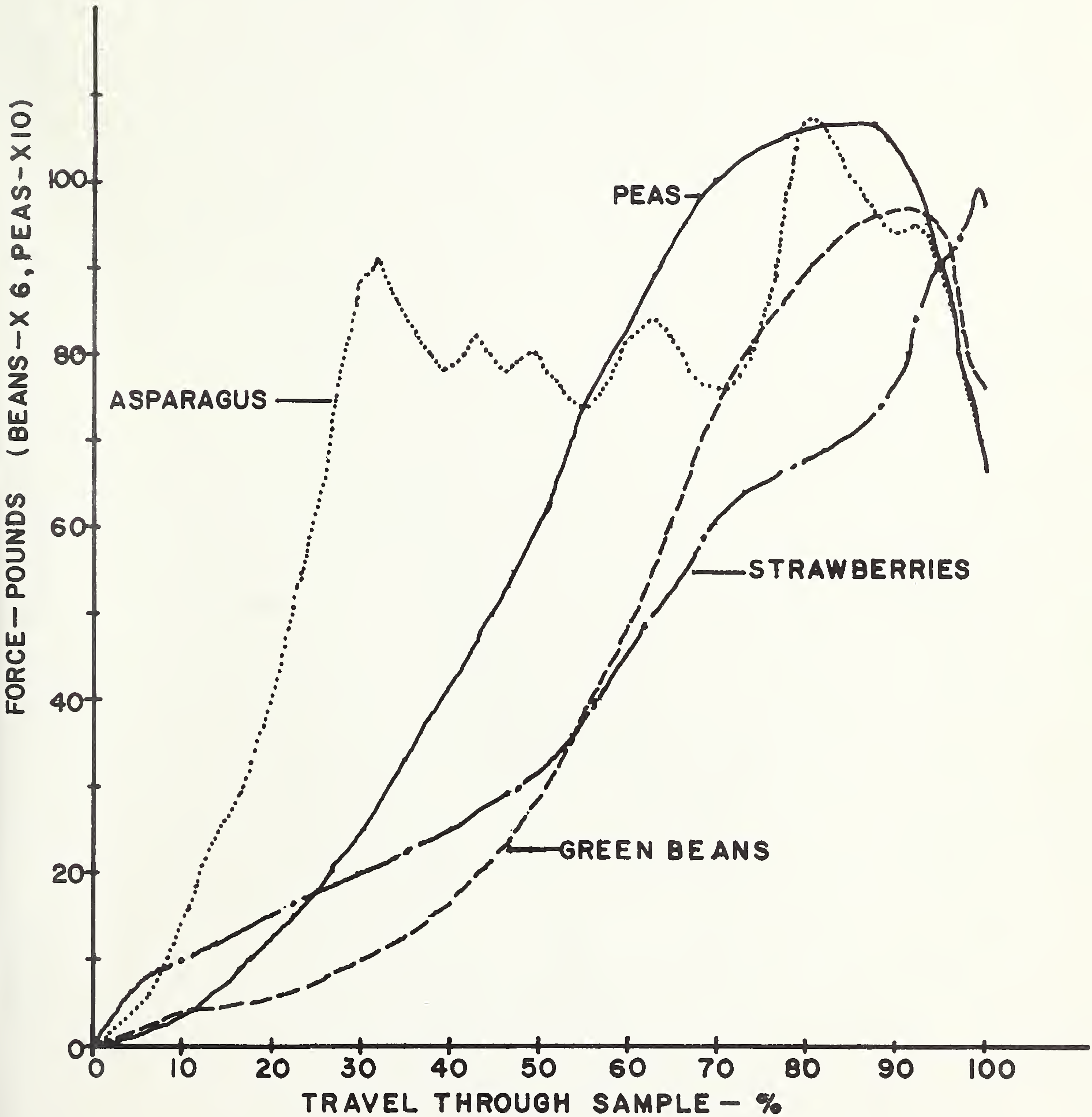

FIGURE 4 - Typical force diagrams of four commodities.